PRODUCTIVE REHABILITATION AND USE OF SALT-AFFECTED LAND THROUGH AFFORESTATION (A REVIEW)

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ABSTRACT

About seven percent of the world's land surface is affected by salinity and sodicity. It is estimated that 20 million hectares of additional land is rendered to zero or negative productivity each year. In irrigated areas, drainage, leaching and soil-amendments are used to reclaim these soils. This traditional approach to ameliorating salt-affected soils is difficult and expensive. The alternative way is the biological approach, which involves selection and planting of salt-tolerant plants for fodder, fuelwood and/or timber production. Salt-tolerant plants have the potential to ameliorate salt-lands and can be grown using poor-quality water.

The most appropriate use for saline/sodic wastelands is the production of high-yielding fuel-wood, fodder and timber species. Economic use of salt-affected wastelands for agricultural purposes has special reference to Pakistan, which has about 5.8 million hectares of salt affected land. At present, it experiences huge recurring losses in terms of limited productivity. Much of these salt-affected lands are suitable for plantation forestry and could be used to help increase supplies of fuel-wood and industrial wood, not available in sufficient quantities to meet the current demand. Tree-based land-management strategies can contribute significantly to both productive uses of salt-affected lands and minimizing the spread of salinity. Suitable technologies have been developed for productive use of these lands through afforestation, using physical, chemical and biological, methods. Recently, a new technique, commonly called auger hole method, has been developed in India, which can be used with great success for afforestation of saline and sodic soils. In this paper, a review of the work done in different parts of the world for rehabilitation of salt-affected wasteland is given.

INTRODUCTION

Approximately 1000 million hectares or seven per cent of the world's land-area is salt-affected (Dudal and Purnell 1986). Estimates given by Dregne et al. (1991) and (Oldeman et al. 1991) suggest that more than 76 M ha of land worldwide has become salt-affected due to human causes (secondary salinity); of this 43 million hectares is irrigated land (in the world's semi-arid and arid regions) and 31 millions hectares is non-irrigated land. Secondary salinisation has resulted through inappropriate water-management in a variety of landscapes, such as by over-irrigation in semi-arid climates (Szabolcs 1989 and Pels 1978) and by clearing of deep-rooted native vegetation in dry land (schofield 1992) and irrigated areas. Salt-affected soils are often found in countries which have regions encompassing, (i) semi-arid and arid climates (e.g. Pakistan, India, USA and Australia) and (ii) seasonally dry tropical climates (e.g. Thailand, Sri Lanka). Secondary salinization has resulted through inappropriate water-management in a variety of landscapes. Pakistan is situated in the south of Himalayan Mountains, between 61^{o} and 76^{o}E and 24^{o} and 37^{o}N. Climatically, it can be divided into 36 ecological zones.

The Salt-affected Soils exist in:

a) Semi-arid and sub-humid Indus plains including all the four provinces (Table-1);
b) Coastal and deltaic regions in the provinces of Sindh and Balochistan;
c) Irrigated semi-arid and arid regions in Punjab, Sindh, Balochistan and NWFP. Some of these areas are irrigated by poor-quality ground water.

This area covers the deserts of Thal, Cholistan, and northern Tharparkar, the piedmont plains of D.G. Khan, Sibi and Kachhi districts; and sub-recent and recent river-plains of the Indus, Jhelum, Chenab, Ravi and Sutlej rivers. The region is the driest part of the lowland area, with rainfall of less than 250 mm, about 80 per cent of which falls in summer. No cultivation is possible without irrigation (Qureshi 1996).

Pakistan is primarily an agricultural economy. It is gratifying that we are blessed with a variety of ecological, climatic and soil conditions. However, despite vast land-resources of about 79.61 million hectares, only 27% of this total area is cultivated, as our valuable soil is subject to various degrading

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Table - 1: Distribution of Arid Regions of Pakistan

Province	Arid (Km^2)	Semi-Arid (Km^2)	Sub-Humid (Km^2)	Other (Km^2)	Total Area (Km^2)
Punjab	119,310	59,678	17,014	10,197	206,199
Sindh	134,896	6,018	-	-	140,914
Balochistan	149,467	197723?	-	-	347,190
NWFP	6,194	16,491	15,160	36,676	74,521
FATA	-	13,580	11,239	2,401	27,220
TOTAL	409,867	293,490	43,413	49,274	796,044
NWFP:	North West Frontier Province		FATA:	Federally Administered Tribal	
Source: *M. Aslam 1987*					

processes, including natural calamities and man-made factors, such as erosion, nutrient depletion, water-logging and salinity.

This loss has been compounded by our gigantic network of irrigation systems, which, on one hand, has brought more of our land under cultivation but at the same time, has raised the water-table, thus causing extensive areas to become waterlogged or salt-affected. The Indus basin has the most extensive irrigation-system in the world. It provides irrigation to about 14.0 million hectares of the agricultural lands of the Pakistan (PARC, 1990). But the vast area of this basin is in the grip of water-logging and salinity. Consequently, the productivity is on a steep decline. Per-acre yields for the country are much below the potential crop-yield, due to various reasons. The most important of these are water-logging and salinity. It is estimated that about 16.2 percent of the total irrigated area had a water-level less than 1.5 meters from surface during June 1993. The latest soil-salinity survey (1977-79) covering 16.72 million hectares of Indus basin indicates that about 25 percent and 38 percent lands have been affected through varying degrees of surface and profile salinity/sodicity, respectively (Table-3).

Considerable efforts are being made to increase the forest-cover of the country. Availability of good-quality agricultural land for afforestation is already limited and increasingly large areas are being taken up for non-agricultural uses, like buildings, roads canals and industries. The only way to increase forest-cover is through Afforestation of unproductive agricultural lands, commonly known as wastelands.

Afforestation of salt-affected soils requires a specialized approach to site-development, choice of species and level of management. Though many tree-species are astonishingly tolerant to adverse conditions, yet to raise viable plant-cover on naturally inhospitable sites requires special attention. The stress faced by the trees depends upon the nature and extent of the problem in soil, which itself is governed by the soil-reaction, nature and amount of soluble salts, physical barriers like hard pan, quality of underground water and depth of water-table, etc. So understanding the soil-problem is a pre-requisite for successful plantation on salt-affected soils. Since the constraints faced by the trees differ, depending upon the type of the soils-problem i.e. sodicity or salinity, the planting-techniques and choice of species also differ in these two situations.

CAUSES OF SALINITY

The main causes of the spread of water-logging and salinity in Pakistan are, the arid climate, flat topography, poor water-management practices, inadequate provision of drainage, insufficient irrigation-supplies for leaching of salts, not restricting irrigation-supplies during periods of no demand, inadequate use of chemical amendments to reclaim sodic and saline

Table - 2: Irrigation-Water Quality-Criteria of WAPADA

Classification	EC_e (dsm^{-1})	SAR	RSC (meq/l)
Useable	<1.5	<10	<2.5
Marginal	1.5 to 3.0	10 to 18	2.5 to 5.0
Hazardous	>3.0	>18	>5.0

soils and use of poor-quality irrigation water without proper management-practices. Irrigation-water quality-criteria of WAPDA, based on measurements of electrical conductivity (EC), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) are given in Table-2.

- **High water-table:** Sub-soil water in the Indus basin has risen close enough to the natural surface-level to cause the moisture to move up by capillary action. The hot sun evaporates this moisture, leaving the salts in soil-profile, as well as on the top crust. The magnitude of salinity depends upon the type of soil-structure, which facilitates capillary action from the groundwater.

- **Hot, dry climate:** Hot dry temperatures cause greater evaporation and, since annual precipitation is much less than annual evaporation, the leaching action by precipitation is nominal. To regain the salt-balance, natural precipitation has to be augmented with irrigation. If the quantity of irrigation-water supply matches evapo-transpiration, then the surface and profile salinity gets washed down below the root- zone, provided adequate drainage is available.

- **Inadequate drainage:** Unless the sub-soil water is below the root-zone, the leaching water will not carry the salts below the root-zone. In the Indus basin, the land is generally flat, the average slope being 1:5000. Efficient natural drainage is a problem. Artificial drainage can be as expensive as the degree of difficulty in extricating and collecting the saline effluent and disposing it through a gravitational or pumped drainage-system.

- **Inadequate irrigation supplies:** Because of the shortage of irrigation-water supplies, farmers resort to thin watering of the fields, leading to insufficient leaching and, consequently, the salts are not washed down below root-zone. The requirement of this parameter are that irrigation-supply should exceed the evapo-transpiration, especially during the hot dry period.

- **Failure to give closure in the irrigation-supplies during periods of no demand:** During the rainy and harvesting seasons, when the irrigation water-demand reduces to almost zero, if canal-closures are not provided, farmers divert the surplus supplies towards the low-lying areas, causing water-logging and consequently, salinity. Utilization of saline soil/water for agriculture and afforestation is now becoming a very important issue for all developing and underdeveloped countries. Accumulation of salts in agricultural lands will eventually lead to a point where alternative (to current Practices) technological methods will become essential to continue agricultural production. International consultants, as well as local experts, have advocated physical and chemical methods of soil-reclamation. While these methods have achieved a measurable success in reclaiming some saline and waterlogged lands, there are numerous problems in extending the same methods to larger regions, namely:

High-energy requirements, large investment cost, management difficulties, etc.

The need to take a new look at the problem has become critical. The latest promising saline agricultural ideas involve revegetation of salt-affected lands, using salt-tolerant trees and fodder-shrubs. This has an added bonus that growing trees might help fulfill local needs for forage and fuel-wood, of which Pakistan has a national shortage.

Table - 3: Extent of surface-salinity in Pakistan

Province	Area Surveyed	Slightly Saline	Moderate Saline	Strongly Saline	Total Saline
Punjab	9,968	0.698	0.399	0.299	1.396
Sindh	5,411	1.028	0.595	0.974	2.597
NWFP	0.55	0.05	0.011	0.011	0.072
Balochistan	0.352	0.06	0.018	0.014	0.092
Pakistan	16.28	1.836	1.023	1.298	4.157

RECLAMATION OF SALT-AFFECTED SOILS

The reclamation process for saline soils normally requires an adequate rate of water-penetration through the soil, for leaching the excess soluble salts from the soil matrix. Successful reclamation of saline sodic soils, however, requires a leaching of excess soluble salts and the replacement of exchangeable sodium from the exchange-complex, with the use of chemical amendments. Additing of chemical amendments or deep ploughing are very useful to increase or maintain hydraulic conductivity during the reclamation process. The rate of transmission of water through the sodic soils primarily depends upon the salt-concentration and sodium-hazard of the water, and upon the exchangeable cation composition, texture, structure, and mineralogy of the soil. Methods of land reclamation are classified into three categories as briefly discussed below.

(a) Physical methods: The physical methods include sub-soiling, deep ploughing, sanding, horizon mixing, profile-inversion and channeling. These treatments increase the permeability of the soil, which is generally a limiting factor during the reclamation of sodic and saline-sodic soils. Deep ploughing is very useful where the sub-soil has gypsum or lime.

(b) Chemical Process: The chemical methods include application of chemicals, such as gypsum, sulphur, sulphuric acid and hydrochloric acid. Gypsum can be applied to all sodic and saline-sodic soils, whilst sulphur, sulphuric acid and hydrochloric acid are only effective for calcareous saline-sodic soils. These amendments finally lower the soil pH, react with soluble carbonates and replace the exchangeable sodium with calcium.

(c) Biological methods: The biological methods include growing of crops on problem-soils and/or their incorporation at the stage of maximum biomass-production. The addition of large amounts of organic matter during reclamation is also a common practice. These methods increase the soil- permeability through root-action, production of aggregating agents during decomposition and the release of carbon dioxide (for dissolving) during respiration and decomposition.

PROPOSALS FOR REHABILITATION

(A) SODIC SOILS

Sodic or black alkali soils, formed under the influence of sodium carbonate, are inhospitable to the establishment of trees and shrubs because:

a) These soils have high pH, which varies between 8.5 to 10.6, when measured on 1:2 soil-water suspension. Not only of the surface but also of lower layers, the pH remains very high.
b) Under natural conditions, the surface 15 cm soil-layer contains excess soluble salts, which are capable of alkaline hydrolysis, such as Na_2CO_3 and $NaHCO_3$. Due to that, electrical conductivity (EC) of surface-soil may be as high as 20 to 30 dSm^{-1}. However, the EC comes down after leaching and cultivation. Soluble Na_2CO_3 and $NaHCO_3$ dissolve organic matter of the soil and impart it black colour. That is why these soils are (many times) referred to as black alkali soils.
c) Such soils have exchangeable sodium percentage (ESP) more than 15. The ESP values of 80 to 90

Table - 4: Province-Wise Chemical Status of Soil profiles

						(% of profiles)
Province /country	**Survey Period**	**No. of Profiles**	**Non-saline - Non sodic**	**Saline**	**Saline Sodic**	**Non-saline sodic**
NWFP	1977-79	1958	79	11	7	2
	1971-75	314	27	50	23	-
Punjab	1977-79	39963	73	7	14	5
	1962-65	23662	55	6	27	11
Sindh	1977-79	20543	38	17	42	2
Balochistan	1977-79	1402	35	26	38	1
Total	1977-79	63866	61	11	24	3
	1962-65	23976	55	6	27	11

Source: *Survey and Research Organization, Planning Division, WAPDA, 1981* are common in surface-layers but decrease with depth.

d) Sodic soils are calcareous in nature and contain $CaCO_3$ ranging from 2 to 40% throughout the soil-profile.
e) Presence of compact $CaCO_3$ layer, which acts as physical barrier for the vertical growth of roots. Such a layer is often observed at a depth of 30 cm to 3 meters below the surface. In eroded soil, sometimes it may be seen just on the surface. Its thickness varies from a few centimeters to about 100 cm.
f) Due to high pH and excess exchangeable sodium, physical properties of these soils are very poor. These soils remain dispersed, resulting in poor infiltration-rate of water. As a consequence of this, surface water-logging is a common feature of these soils during rainy season. Similarly, due to poor structure, air movement is also restricted. Thus roots die due to excessive water and low availability of water.
f) When dry, these soils become very hard, crack and give rise to poor tilth.
g) Low availability of nutrients like N, Ca, Zn and Fe, due to high pH and low organic matter content. These soils are generally medium to high in available phosphorus and potassium.

Classification of soil Sodicity

Soils become sodic when the exchange-surfaces become dominated by sodium instead of calcium ions. And mostly, it is classified in terms of the Sodium Adsorption Ratio (SAR) of the soil-saturation extract. In the field, it is checked with pH value; if the pH value reaches 8.5 or above, the soil is sodic. Four classes of Soil Sodicity in terms of SAR as recognized by the USDA are given in Table-5.

PLANTING METHODS FOR SODIC SOILS

Raising trees on sodic soils requires modification in the root-environment by;

a) Amending the chemical nature of soil for optimum growth of roots, leaching of salts and maximum retention of soil-moisture;
b) Breaking the hard pan by perforation so as to permit vertical growth of roots; and
c) Proper maintenance of soil-fertility through application of fertilizers and manure.

Since the site-preparation is the costliest and time-consuming operation, considerable planning is required for optimizing this aspect. The technique, to be adopted for afforestation of sodic soils, is mainly governed by site and soil conditions, species to be planted and the purpose of the plantation. Based on the above concepts, development of sodic soils for afforestation involves the following components:

1. Site preparation

For successful plantation of trees for timber-production and orchard establishment, pits of higher dimensions i.e. 90x90x90cm should be used. In these pits, hard $CaCO_3$ layer should be perforated, with the help of mechanical auger, to a depth of 180cm. The diameter of the posthole may vary from 15 to 30cm. Shallow pits i.e. 60x60x60cm or 45x45x45cm can be used for energy-plantation, especially where Prosopis juliflora is being planted. However, breaking of hard layer through mechanical auger is a must for proper growth of all other plant-species (Gill and Abrol 1985).

2. Method of refilling pits/auger holes and composition of filling-mixture

After digging of pits, it is necessary that these should be filled back with appropriate mixture as soon as possible. Points to be noted are:

a) Addition through loose salt-rich surface-soil and through wind;
b) Rainwater may fill the pits with salt-rich surface run-off from adjoining areas and thus increase the

Table - 5: Classes of Soil Sodicity

Sodicity Classes	Sodium Adsorption Ratio (SAR)
Non-sodic	Less than 15
Slightly-sodic	15 to 25
Moderately-sodic	25 to 45
Strongly-sodic	More than 45

concentration of toxic soluble salts, like Na_2CO_3 and $NaHCO_3$, which are harmful for the roots. If the pits get filled with run-off water, then these should be drained and the fine clay deposited inside should be scraped out before refilling;

c) After a number of rains, it is difficult to mix amendment, farm-yard manure (FYM) and rice-husk (RH) with sticky sodic soil and properly fill back the pit; and

d) If the pits are filled before the rainy season then the rainwater can be used for dissolution of amendment and leaching of salts from the pit.

While refilling the postholes, soils should be properly packed, so as to avoid serious settling down at later stages, which can affect the establishment of seedlings. After filling the pit, a raised earthen bund should be made around it (with the amended soil), so as to prevent the entry of salt-rich run-off water into the pit.

Composition of filling-mixture has a profound effect on the survival and growth of the tree species. Based on extensive research (Sandhu and Abrol 1981, Gill and Abrol 1985, Chhabra and Abrol 1986, Singh and Abrol 1986) it has been observed that addition of chemical amendments, like gypsum and pyrite, is a must for survival of almost all the tree-species raised on sodic soils. Addition of FYM improved the physical environment as well as supplies of nutrients, like N, Fe, Mn and Zn. Application of physical amendments like RH and sand improves the leaching of salts and aeration, which are limited factors in sodic soils.

The following filling mixtures have been found suitable for various purposes:

i) Shallow pits/auger holes for energy plantation: 3 kg gypsum, 3 kg FYM, 3 kg RH.

ii) Deep pits/auger holes for Timber production: 5 kg gypsum, 5 kg FYM, 5 kg RH.

iii) Deep pits for orchard plantation: 10 kg gypsum, 10 kg FYM, 5 kg RH.

Replacement of bad-quality sodic soils of the pit/auger holes with good-quality normal soil (sometimes referred to as sweet soil) has been proven good and can be adopted wherever economical. When texture of soil is heavy, addition of 5-kg sand is beneficial. However, in light-textured soils, addition of (rice husk) RH alone is enough to improve the physical environment. The quantity of amendment depends upon the volume of the soil ($\pi r^2 h$) i.e. volume of the augur-hole or pit and choice of the tree-species. Similarly, gypsum requirement for exotic species is more than that for the local species.

3. Choice of Species

In order to obtain maximum production from saline land, it is vital to choose the correct species, land-preparation, planting techniques and tree-growing systems. Species choice will depend on a range of soil and climatic factors, including degree of soil-salinity, and whether wood and/or non-wood products are desired. Based on relative tolerance of salt and local agro-climatic conditions of the site, a list of species is given in Table-6.

a) *Energy plantation:* For energy plantation, that species should be considered, which can tolerate adverse soil-conditions, have higher rate of growth, can fix atmospheric nitrogen through symbiosis, tolerate drought, respond easily to coppicing, improve soil-conditions through intense biological activities of their roots and N-rich litter and does not require special nursery preparations. Species like: Mesquit (Prosopis juliflora), Kikar (Acacia nilotica), Sesbania (Sesbania aegyptica), Casuarina (Casuarina equisetifolia), Eucalyptus (Eucalyptus camaldulensis), Siris (Albizia lebbeck), Parkinsonia (Parkinsonia aculeata), Iple Iple (Leucaena leucocephala) and Sukh chain (Pongamia glabara syn Derris indica) are suitable species.

b) *Timber and Small products:* For this purpose, species like Kikar (Acacia nilotica), Casuarina (Casuarina equisetifolia), Siris (Albizia lebbeck), Eucalyptus (Eucalyptus camaldulensis), Arjun (Terminalia Arjuna), Neem (Azadirachta indica), Jamun (Syzygium cumini), Jand (Prosopis cineraria), Mesquit (Prosopis Juliflora), Imli (Tamarindus indica), Frash (Tamarix aphylla) jungle jallebi (Pethecellobium dulce), etc., are suitable.

c) *Orchard Plantation:* Depending upon intensity of management, agro-climatic conditions and social needs, different fruit-species can be considered: Guava (Pisidium guajava), Aamla (Phallyanthus emblica), Ber (Zizyphus mauritiana), Date-Palm (Pheonix dactylifera), Phalsa (Grewia subinae). For ber, the plantation should be done with wild variety and, after the establishment of the rootstock, budding with good quality scion should be done in situ.

d) *Grasses and Shrubs:* Since these wastelands are also used for grazing animals, it is desirable that, in addition to growing trees, suitable grasses and shrubs should also be raised on these lands. In addition to providing much-needed fodder, these grasses will also hasten the reclamation process, through activities of roots and biological harvesting of salts.

For sodic soils, the most tolerant is kallar grass (Diplachne fusca) syn. (Leptochloa fusca). This grass can tolerate high pH/ESP and the waterlogging which is quite common in these soils. This grass is raised usually from cuttings, but it can also be raised from

Table - 6: Rating of selected tree and shrub species to root-zone soil-salinity, sodicity and water logging. Salinity is expressed as EC^e in dSm^{-1} [moderate (4-8), high (8-16), severe (>16)]. Soil sodicity is expressed in terms of pH [moderate (8.0-9.0), high (9-0-10-0), and severe (>10.0)]. Modified from Marcar and Khanna (1997)

Species	Salinity	Sodicity	Water logging
*Acacia ampliceps**	Severe [b]	Severe [b,k]	No [b]
*A. nilotica**	Moderate [a]	High [a]	-
A. saligna	Moderate [a,b]	Moderate	-
A. stenophylla	Severe [b]	Severe [b,k]	Yes [b]
A. tortilis	Moderate [d]	-	-
Ailanthus excelsa	High [a]	Moderate [f]	-
Albizia lebbeck	Moderate [a,c]	Moderate [a,f]	-
A. procera	-	Moderate [f]	Yes [i]
Azadirachta indica	Moderate [a,c]	-	-
Butea monosperma	Moderate [a,c]	High [f]	-
Casuarina equisetifolia	Moderate [a]	High [a,f]	Yes [b]
*C. galuca**	High [a,b,e]	Moderate/high [b]	Yes [b]
*C. obesa**	High/severe [b,j]	High [b,k]	-
Conocarpus lancifolius	High [a]	-	-
Dalbergia sissoo	Moderate [a]	Moderate/high [f]	-
*Eucalyptus camaldulensis**	Moderate/high [a,b,d,]	High [a,b,k]	Yes [b,h,i]
E. citriodora	Moderate [a]	-	-
*E. tereticornis**	Moderate/high [a,b,e]	High	
Leucaena leucocephala	Low/moderate	Moderate [f]	
Parkinsonia aculeata	Moderate [a]	-	Yes [b]
Pongamia pinnata	Moderate [c]	-	-
Prosopis juliflora	Severe [a,d]	High [k]	Yes [h]
Tamarix aphylla	Severe [a,d]	-	Yes
Tamarix articulata	Severe [a]	-	Yes [a]
Terminalia arjuna	High [a,c]	Moderate/high [f]	-
Zizyphus jujuba	High [a]	-	Yes [i]

Notes: *Species marked with asterisk (*) are known to exhibit marked provenance response on saline soils. Selected references are given foe species classification, where available: [a] Gill and Abrol 1991: [b] Marcar et al. 1995b; [c] Yadav and Singh 1970; [d] Jain et al.1985; [e] Dunn et al. 1995; [f] Yadav 1980; [g] Benyon et al. 1999; [h] Singh et al. 1989; iBangash 1977, [j] Van der Moezel et al. 1988; [k] Hussain and Gul 1992. Adopted from Marcar, N.E., Ismail, S., Hossain, A.K.M.A., and Ahmad, R. 1999. Trees, shrubs and grasses for saltlands: an annotated bibliography. ACIAR Monograph No. 56, 316 PP.*

seeds. Other promising grasses for sodic soils are Khabal (Cynodon dactylon), sanwak (Echinochloa crusgalli), Buffle grass (Cenchrus ciliaris), Para grass (Brachiaria mutica), Rhodes grass (Chloris gayana), and Blue panic (Panicum antidotale). Among shrubs, salt bush (Atriplex amnicola) and (A. lentiformis) have been found equally useful for cultivation in highly affected lands. Grass species like Puccinellia (Puccinellia ciliata), tall wheat grass (Thinopyrum elongatum) can also be tried.

4. Time of Planting

Field conditions at the time of planting, and during the first few months after planting, are of critical importance. The best time for any planting is when the soil is moist and warm, but not waterlogged. For most of the areas, saplings should be planted in the field after the onset of monsoon rains (July-Sept.). It is advisable that the first two or three rain-showers should be used to flush out salts accumulated on the surface, to leach salts of the pit and to allow the soil in the pit to settle down. This will provide salt-free and amended environment for the better establishment of young plants. Once the plants are established, then warm and humid climate during this period helps in rapid growth of young saplings.

Trees planted in spring need regular irrigation until the rainy season, because the climate from April to June is usually very hot and dry. This, in addition to increasing the water-demand of growing plants, also results in higher accumulation of salts in the root-environment. To mitigate the effect of harsh temperature and high salts, frequent irrigation with good-quality water will be required. Normally, survival of the saplings planted in spring is low when the assured irrigation is lacking.

5. Irrigation

Irrigation during initial stages of development and growth, is essential for trees raised on sodic soils. As the distribution of rainfall even in the rainy season is uneven, there may be periods of long drought, necessitating irrigation in the rainy season too. Depending upon the climatic conditions, distribution and frequency of rainfall, the irrigation should be applied at least once in 7 days in the first three months and then once in a month for at least one year. Even at the latter stages, protective irrigation is required in sodic soils. Frequency of irrigation should be more in shallow pits, as compared to deeper pits.

As the surface of soil contains high concentration of salts, flood-method of irrigation should be avoided in the first year of planting. Spot-irrigation with the help of containers/pipes will be more useful. At later stages, irrigation can be done through channels joining the various pits. However, to avoid salts accumulating on the ridges of channels connecting the pits, application of gypsum in the channel and on the ridges will be of great help. Physical removal of salts (wherever possible), especially in the first year, can be useful.

7. Drainage

Most of the trees are sensitive to extra water in the root-zone. During rainy season, sodic soils due to their poor infiltration-rate experience floods. This excess water can cause temporary waterlogging and kill the young plants. To avoid this, excess rainwater should be drained, through surface drains, immediately.

However, efforts should be made to retain rainwater, as much as possible within the field. This can be done by making bunds around the field. These bunds will also prevent entry of extra water. Conservation of rainwater in small flat plots can be useful, as submergence caused by it helps in ameliorating the sodic soils by enhancing the dissolution of native $CaCO_3$. Ahmad and Chang (2000) stated that sub-soil tillage operations, such as chiseling or mould board or disc ploughing on land with compact layers, hard pans or cemented layers, improved infiltration of water and deep penetration. This will aid in removal of salt and sodium, as well as preventing their accumulation. Chang et al. (2001) recommended that reduction in soil-salinity, combined with appreciable increase in crop-production is possible in saline soils through use of deep ploughing.

8. Fertilization

Despite the fact that nutrients may be harder to obtain from salt-affected soil than unaffected soils, small quantities of slow-release may be useful, as early growth-responses to fertilizer may be very beneficial. For sustained high growth-rates, fertilizer application is probably essential on most sites. If soil pH is high, responses to fertilizer-application are often significant.

Sodic soils are rich in available phosphorus and potassium (Chhabra 1985). There is no need to apply these nutrients at the time of planting. Nitrogen is the most limited nutrient and, thus, trees like eucalyptus and other such plants, which can't fix atmospheric nitrogen through symbiosis, need chemical fertilizers. Nitrogen @ 25g per plant mixed in the filling-mixture and its regular application every year has proved beneficial for eucalyptus (Chhabra and Abrol 1986). Application of nitrogen at higher doses may damage the plants, so only lower doses of N i.e. 25g to 50g per plant, and that too with assured irrigation, should be provided. To avoid Zn deficiency 10g of $ZnSO_4$ per plant should be applied in the filling mixture. Sometimes Fe-chlorosis due to high pH and $CACO_3$ induced iron-unavailability, has been observed in eucalyptus grown on sodic soils. Application of pyrites and FTM does help in meeting the iron needs of the trees. Fertilizers should be applied in the months of April and September when fresh growth starts.

9. Mulching

Mulches help to reduce loss of moisture from the soil and therefore reduce the accumulation of salts at the surface. Mulches reduce evaporation by lowering surface-soil temperatures and acting as barrier to free water movement. This reduces the rate of water-movement to the soil-surface from wetter conditions below. Effective mulches include wood chips, straw (hay), rice hulls, vermiculite, peat and sand. These mulches should be at least 5 cm thick and should be applied to an area of 80 cm to 1 m in diameter around the plant-stem plantation. Mulches also reduce weed-competition.

10. Spacing and Pruning

It is an established fact that increase in number of plants per unit area, gives an increase in total biomass-production, although the biomass per tree decreases. So, for energy plantation, the distance can be as close as 1m from plant to plant and row to row. Since, the overall growth of trees in sodic soils, is less than its growth in normal soils it is observed that planting-distance can be reduced from 3x3 m to 1.5x1.5 m in case of eucalyptus. In sodic soils, closer planting also partially covers the risk of high mortality. For timber-production, the distance can be regulated later by selective felling.

Except for eucalyptus, stem (about1/3 of height) should be pruned annually to remove unwanted branches. This helps in accelerating the growth of the tree, improving the quality of wood and also promoting the growth of under-story vegetation. Pruning should be done before the onset of spring i.e. in January or February.

11. Mixed Plantation

Considering the hostile soil-conditions, mortality of young saplings of many species in the initial stages may be considerable. Some species grow much slower and require long time for economic exploitation. In view of this and to avoid complete failure, instead of monoculture, planting should be done with mixed species. Since Prosopis julifllora is quite tolerant and can provide good cover in the initial years, 50 to 70 per cent planting should be done with it, and the rest with other species. The distance between two rows and level of site-preparation should be so adjusted that big plants come in bigger pits and at wider spacing, while plants like mesquite and sesbania come in small pits and at closer spacing. At the later stages, lower-story plants can be harvested for fuelwood-production while others can continue to grow for timber/fruit production. However, while mixing species their growing habits (aggressive index) should be kept in mind.

B) SALINE SOILS

The accumulation of excessive levels of soluble salts in the root-zone of plants is called the "salinization process" and the soils so developed are called salt-affected soils. Saline soils contain excess soluble salts, $ECe>4dSm^{-1}$, have pH<8.2 and exchangeable sodium percentages less than 15. These soluble salts mainly consist of Cl and SO_4 of Na Ca and Mg. Those present in relatively smaller amounts are the ions of potassium, carbonate, nitrate, borate and lithium. The plant-growth in saline soils is affected by high osmotic pressure of soluble salts, resulting in low water availability, toxic effects of soluble ions, especially Na, Cl, and SO_4, and low availability of nutrients. The main source of these salts in the Indus basin is mineral weathering systems, ground water and irrigation, which redistribute the accumulated salts. The high evaporation-rate and the shallow depth of the groundwater, allows the salts to move up with moisture, through capillary action near to soil surface, and accumulate in the top soil. Soil concentrations in the soil vary both vertically and horizontally, depending upon such conditions as variation in texture, plant-growth and hydraulic conductivity. The extent of salinization is governed by the rate of evaporation of saline water and the counteraction of leaching water from precipitation and irrigation. Classification of Salt-affected soils, considering both EC_e and ESP, are given in Table-7.

In arid saline soils, the plants face stress due to excessive accumulation of salts in the root-zone while in waterlogged saline soils or saline soils with shallow water table, both the salinity and water-logging affect the growth of tree species.

Although salts affect plant-growth in many ways, the three most important are:

1. Salts cause a reduction in the rate and amount of water that can be withdrawn from the soil by plant-roots due to increased osmotic pressure. According to Hayward and Waldleigh (1949), plant-growth is retarded almost linearly with increase in osmotic pressure.

2. Common salts like sodium, bicarbonate, and chloride are toxic to some plants when present in higher than normal concentrations. The toxic effects are usually critical during the germination-period in the 5 cm to 7 cm surface-soil zones. Besides causing specific toxic effects, salinity can induce nutrient deficiencies or imbalances in plants. The specific effects vary among species and even among varieties of a given crop. Excessive salinity can affect: 1) nutrient-availability, 2) nutrient-uptake and/or distribution within the plant, and/or 3) the internal plant-requirement for a nutrient element through physiological inactivation (Gratten and Grieve 1992). One example is Na^+ induced $Ca2^+$ deficiencies, which occur when the $Na^+/Ca2^+$ ratio in a saline solution exceeds a certain threshold level.

3. Certain salts, sodium being the best known, when present in high concentrations, can affect the physical conditions of the soil. Soils with excess sodium tend to puddle, have poor structure, and develop poor infiltration and hydraulic conductivity rates.

Table - 7: Classification of Salt-affected Soils

Soil	EC_e (dSm^{-1})	ESP	pH	General characteristics
Normal	<4	<15	<8.5	Normal soils with no salt encrustation on the surface
Saline	4 or >4	<15	<8.5	Locally, these soils are called as “Thur” with white salt encrustation on the surface during winter. These soils are flocculated with good permeability to water and can be reclaimed by simple leaching with water no amendment is needed for reclamation
Saline-sodic	>4	>15	About 8.5	Locally, these soils are called “Thur Bara”, appearance similar to saline soils, sodium tends to disperse and deflocculates the soil and decreases its permeability to air and water. Application of amendments is essential for effective reclamation.
Sodic	<4	>15	8.5 to 10.0	Locally, these soils are called “Bara”. These soils are generally dispersed; the infiltration, drainage, and aeration are poor. Seed germination, seed emergence and plant-growth are also poor. Darkening of soil-surface due to dispersed and dissolved organic matter, present in the soil-solution of highly alkaline soils, may be deposited on the surface after the evaporation of water. For this reason, such soils are also called “Black alkali soils”

Source: *Drainage Manual, U.S. Bureau of Reclamation, 1978*

For such soils, care has to be taken to prevent excessive salt-accumulation and to provide aeration in the root-zone. Before these soils can be farmed successfully, salts must be removed, chemically, by replacing the excessive sodium with calcium and installing a drainage system to facilitate leaching out replaced sodium salts.

Plant-Response to Salinity

The most common plant-response to salt-stress is a general reduction in growth and yield. As salt concentrations increase above a threshold level, both growth-rate and ultimate size of plants progressively decrease. However, the threshold and the rate of growth reduction vary widely among different plant-species. Growth-suppression seems to be a non-specific salt effect that is directly related to the total concentration of soluble salts or osmotic potential of the soil water. Within limits, osmotic concentrations of different combinations of salt cause nearly equal reduction in growth. On the other hand, single salt or extreme ion ratios are likely to cause specific ion effects, viz. Ion toxicity or nutritional imbalances which cause even further yield-reduction. Plants can accumulate Cl^-, Na^+, or both to toxic levels, which cause leaf burn, necrosis, and defoliation. Toxic concentrations of Na^+ or Cl^- in leaves may limit growth of severely stressed plants; moderate levels of salinity can cause significant reduction in growth and yield of most crops, without evidence of toxicity and foliar injury (Maas 1996).

PLANTING METHODS FOR SALINE SOILS

The most promising techniques for afforestation of saline soils are:

a) *Ridge-trench method:* In this method, trees are planted on ridges, 50 to 100 cm high, and trenches between the ridges are used for draining excess water. However, in plain and especially under arid conditions, the salts have tendency to accumulate on the surface. Under such conditions, due to more evaporation from the exposed area and little leaching during monsoon, excess accumulation takes place on the sides and on the top of the ridges. Further, as a result of more evaporation, moisture-content is generally lower in the ridges than in the original land-configuration. Thus, plant-roots face excess salts and low moisture-conditions, making survival harder. However, this technique is suitable only near the sea coast, where rainfall is normally high and this helps in leaching of salts from the ridges, providing stress-free environment.

b) *Sub-surface planting in auger hole*: Since in the saline soils, maximum salt-accumulation takes place on the surface, greater success can be achieved if the young roots are planted in the subsurface, which contain low salts. Planting of saplings in the auger hole, 30-45 cm below the surface, helps in avoiding the zone of excess salts and the roots are exposed to only the intermediate salinity, which corresponds to the transmission-zone salinity of the soil. However, the auger-hole collapses many times due to run-off from adjoining areas and the salts accumulate there. Further, sub-surface salinity is much lower than surface-salinity, yet it may be high enough to kill the plants in the initial critical stage of establishment.

c) *Planting in furrow-cum-irrigation channels*: In this technique, the young saplings are planted in the shallow trenches or furrows, 30 cm deep, which are also used for irrigation. The water in the furrow pushes the salts away from the active root-zone of plants and also serves as a source of irrigation.

1. Amendments for afforestation in Saline soils

Chemical amendments like gypsum or pyrite is not needed to increase the rate of plantation in saline soils. However, in case of heavy-textured soils, addition of sand, Silt, rice husk, etc., improve the physical environment and help in more efficient leaching of salts. Application of organic mulch also helps in reducing the accumulation of salts on the surface. In case of areas having high RSC waters, regular use of gypsum to counteract the harmful effects of CO_3 and HCO_3 of irrigation water is beneficial.

2. Irrigation

Regular irrigation to plants, especially in the initial period of establishment, is essential for afforestation of saline soils. In spite of the fact that in many areas, due to shallow water-table, the soils may look moist and have enough water, even then irrigation with good-quality water is a must. This is mainly to leach down

Table - 8: Grass and Shrub species that have been evaluated for their salt-tolerance and productivity. Salinity is expressed as EC_e in dSm^{-1} [moderate (4-8), high (8-16), severe (>16)]. Modified from Ahmad and Ismail (1993)

Less tolerant	Moderately tolerant	Highly tolerant
Grasses		
Cenchrus setigerus b *Dichanthium annulatum b* *Panicum turgidum a* *Pennisetum typhoides c* *Sporobolus arabicus a*	*Distichlis spicata f* *Leptochloa fusca a* *Sporobolus aeroides **	*Cynodon dactylon g* *Eleytrigia elongatum h* *Festuca elaitor g* *Juncus acutus l* *J. rigidus l* *Paspalum vaginatum g* *Puccinellia ciliata l* *P. distans k* *Spatina alterniflora f* *Sporobolus helvolus h*
Shrubs		
Clitorea ternatead d *Indigofera oblongifolia a* *Leucaena leucocephala a* *Sesbania aegyptica e* *S. bispinosa** *S. sesbana*	*Atriplex cinerea** *A. patula** *A. undulata** *Kosteletzkya virgibica f*	*Arthrocnemum fruticosum g* *Atriplex amnicola l,n* *A. lentiformis l* *A. nummularia o* *Maireana brevifolia** *Salsola iberica m* *Tamarix aphylla l*

Source: *Modified from Ahmad and Ismail (1993). Notes: Relevant references are: [a] Ahmad et al. 1986; [b] Ahmad 1997; [c] Anon 1990; [d] Saeed 1994; [e] Ahmad and Zaheer 1994; [f] Gallagher 1985; [g] Pasternak et al. 1986; [m] Fowler et al. 1985; [n] Aslam et al. 1986; [o] Greenway 1968; *Ismail et al. (Unpublished data). Adopted from Marcar, N.E., Ismail, S., Hossain, A.K.M.A., and Ahmad, R. 1999. Trees, shrubs and grasses for saltlands: an annotated bibliography. ACIAR Monograph No. 56, 316 PP.*

the salts from the root-zone and thereby provide stress-free environment. For successful establishment of plants, at least 8 to 10 irrigations should be provided in the first year and 3 to 6 in the second year of plantation. Even at later stages, irrigation should be provided wherever available.

3. Tree species suitable for saline soils

Tree species differ in their ability to withstand salinity and aeration stress, individually and simultaneously. In areas where salinity is not associated with shallow water-table conditions, species like Terminalia arjuna and Leucaena leucucephala, etc., can be grown. Where high salinity and shallow water-table exist together, species like Casuarina glauca, C. equisetifolia, Tamarix aphylla and Prosopis juliflora can be grown. For moderate salinity, 10-22 dSm^{-1}, species like Acacia nilotica; Casuarina equisetifolia and Eucalyptus camaldulensis can be grown. Grasses and shrubs which can be tried in saline areas are given in Table-8.

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